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TITLE: ENERGY BALANCE IN MILITARY RECRUITS PERFORMING INTENSE PHYSICAL EFFORTS UNDER EXTREME CLIMATE CONDITIONS

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Energy cost of field operations has been as yet mainly predicted rather than measured accurately. We assessed the energetic status of soldiers exposed to intense physical activities and cold weather. Subjects (n=19) performing routine field manoeuvre under conditions of 0-12°c, 75-100% RH were followed up for 12 days. Energy expenditure (EE) was measured by the doubly-labelled water (DLW) technique, after a single, oral dosing of $^{2}H_2{}^{18}O$. Energy intake (EI) was assessed from detailed food records filled up at "real-time" and analyzed by computerized food charts. Energy balance (EB) was calculated as the difference between EI and EE for each subject. Mean (±SD) body weight (BW) changed from 72.0±7.9 to 70.9±6.9 kg during the study. Daily EI was 2409±418 and daily total EE was 4249±645

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kcal/24h of which ~48% were estimated as basal metabolic rate and the rest as the cost of physical activities. Mean EB of -1790±637 kcal/24h was calculated. Under these conditions EI does not always meet the augmented requirements to operate and maintain body temperature. This discrepancy, if prolonged, results in a negative EB and a change in BW and body composition.

ENERGY BALANCE IN MILITARY RECRUITS

PERFORMING INTENSE PHYSICAL EFFORTS

UNDER EXTREME CLIMATIC CONDITIONS

INTRODUCTION

Energy balance of infantry soldiers during actual military maneuvers has not been thoroughly studied. Estimates have been obtained from studies carried out under field training conditions (1-3). These investigations reported a high energy expenditure, which were not always compensated by an adequate energy intake (3). Military operations can often involve long periods of complete immobilization in a cold environment, which can further limit the application of field training results to actual combat conditions. Exposure to a continuous cold stress is expected to increase the energy expenditure more than two folds with carbohydrates serving as the main fuel for this enhanced thermogenesis (4). Furthermore, the metabolic cost of any physical activity is greater when performed in the cold than in a comfortable climate (5). This has been supported by Shephard and others (6,7) reporting a high energy expenditure at the range of 4000-6000 kcal/day in expeditions to the Poles.

The measurement of total energy expenditure using the doubly labeled water (DLW) method (8) lends itself to measurements under combat conditions, since it does not interfere with the routine activities of troops. We have studied energy balance in soldiers on actual maneuvers, using

the DLW technique and food records to determine whether energy balance studies carried out under field training conditions are representative of combat conditions in cold weather.

SUBJECTS AND METHODS

Subjects: Eighteen male infantry soldiers, aged 19-20 years old, volunteered to participate in the study. The physical characteristics of the subjects are given in table 1. At the time of the study, the subjects had been on active duty for a year and had completed a one infantry training course, achieving a similar level of physical performance. The subjects gave their written informed consent after being explained the purpose and procedures involved in the study. The protocol was reviewed and approved by the Ethics Committee of the Israel Defense Forces Medical Corps.

Protocol: The study was carried out during rainy, winter months on mountainous terrain in the Upper Galilee region of Israel. Dosage, sampling and data collection was carried out in the unit's fortified base. The general scheme of the protocol is shown in figure 1.

Prior to the start of the study, daily urine samples were collected for three days for baseline isotopic analyses. Samples of the tap water at the base camp were also taken. Starting one week prior to the start of the study and during the course of the study, the subjects did not leave the base

camp, except for maneuvers and their sole source of drinking water was base camp tap water.

The subjects were divided into two groups, who were studied serially. Within each group (n=9) seven subjects received doubly labeled water; two subjects served as controls in a blinded fashion and received a dose of tap water, for monitoring changes in background isotopic levels.

The height and weight of the subjects was measured immediately after voiding. Weight was measured to within ± 10 gram on a digital scale and the total dosage of doubly labeled water for each study group was calculated accordingly. A few hours prior to the start of the study, deuterium oxide (99.8%, E. Merck D-6100 Darmstadt, Germany) was weighed into 10% oxygen-18 enriched water (Iso-Yeda, Rehovot, Israel). Aliquots of the doubly labeled water were weighed out for each subject to provide a dosage of 0.07 g/kg body weight $^{2}H_2O$ and 0.174 g/kg body weight $H_2{}^{18}O$. The dosages were stored in glass containers, whose caps were sealed with Parafilm. Control dosages of base camp tap water were stored in identical containers.

The subjects refrained from eating three hours before and three hours following dosing. Immediately prior to receiving the dose, the subjects voided. The subjects then drank the dose, using a straw carefully inserted through a Parafilm seal into the bottle to avoid spilling or exchange of the labeled water with atmospheric moisture. The bottle was then rinsed with 100 ml of tap water, which was drunk

using the same straw. Urine samples were collected after 8 hours and then daily at the same time of day for the next 12 days. In cases where the subjects were away on field maneuvers away for more than 24 hours, urine samples were taken immediately prior to departure and upon return to the base.

Aliqots (20 ml) of the urine samples were then frozen for subsequent isotopic analysis. A single 24 hour urine collection was stored for nitrogen analysis. Body weight was measured again on the last day of the study at the same time of day as the initial weighing and after voiding.

Activity patterns: A daily log of activities of every subject was recorded by one subject in each group. Before each maneuver, subjects were weighed together with their equipment load. During maneuvers, the nature of the mission, distance traveled to and from the target, grade and type of terrain, speed of the march, climatic conditions and any contacts or special events that occurred during the mission were recorded. Heart rate measurements, during maneuvers, were made in 11 subjects over a 16 hour period using a Uniq CIC Rotronic Heart Watch.

Diets: The subjects were allowed to eat ad libitum. Daily food consumption was recorded by each subject on food record cards over the entire study. Subjects recorded their food intakes under the supervision of trained nutritionist and when eating snacks between meals. Records were collected at the end of each day and were reviewed by the nutritionist. During maneuvers, entries of food consumption were made by each subject and were collected and reviewed upon their return to base camp.

Climatic conditions: Temperature and relative humidity were measured using a Rotronic Hygroskip and wind speed was measured using an anemometer three times a day at 8:00, 14:00 and 20:00.

Doubly labeled water isotopic analyses: Total free living energy expenditure was measured using the doubly labeled water method, whose principle, method of calculation, validation and sources of error have been reviewed by Coward (1988) (8). The isotopic enrichment levels were measured using a VG Isogas Aquasira dual isotope-ratio mass-spectrometer (VG Isogas, Ltd., Middlewich, Cheshire, U.K.). CO2 production rates (FCO2) were calculated using Coward's modification (9) of the original Lifson's formula (10)

$$FCO_2 = 1/2\ (K_O D_O/I_O - K_D D_D/I_D)$$

where K_O and K_D are rate-constants for ^{18}O and ^{2}H disappearance, D_O and D_D are doses of ^{18}O and ^{2}H, and I_O and I_D are zero-time intercepts of the ^{18}O and ^{2}H disappearance curves.

Fractionation corrections were incorporated into the equation (1) using values of 0.99 for $^{2}H_2O$, 1.04 for $C^{18}O_2$ and 0.93 for $H_2{}^{18}O_2$ to give:

$$FCO_2 = 1/2[0.99 \times K_D V_D/I_D + (1-X) K_D V_D/I_D + 1{\cdot}04$$
$$K_O V_O/I_O] - 1/2[0{\cdot}93 \times K_D V_D/I_D + (1-X) K_D V_D/I_D]$$

where X represents the fraction of water undergoing isotopic fractionation and is set at 0.35.FCO_2 values were converted to energy expenditure using stsndard calorimetric equation of Weir (11) and an assumed mean respiratory quotient of 0.85.

Laboratory Analyses: Total urinary nitrogen in a 24 hour urine collection was determined by the Kjeldahl method. Protein oxidation rate (g/day) was calculated by multiplying the total urinary nitrogen by 6.25.

Energy Intake: The nutrient composition for each dietary entry in each subject's food record, was estimated by a computer method based on standard tables prepared by the Military Nutrition Division of the Israel Defense Forces. This data was used to calculate individual daily caloric intakes. Intakes were calculated separately for food items provided by the base camp and food items obtained privately by each subject. The daily caloric intakes over the 12 day period were used to calculate the average individual daily energy intakes.

Energy and protein balance: Individual energy balances were calculated as the difference between average individual daily energy intake and expenditure. Mean values for the entire group were obtained from these data. Protein balance was calculated similarly.

Statistics: Data are given as mean ± standard deviation.

RESULTS

Base-line isotopic abundance: The relatively small change in isotopic abundances in the receiving tap water indicated that the subjects were already at isotopic equilibrium with the local water supply at the start of the study. There was no need to correct the isotopic abundances of the subjects that received a dose of enriched water.

Total Body Water and Body Composition: The total body water (kg), fat free mass (FFM) (kg) and percent fat mass of each of the 14 subjects that received the labeled water are given in table 1. The mean percent total body water was 42.2±2.8 kg and the FFM 57.9±3.8 kg.

Energy Expenditure: The individual mean daily energy expenditures ranged between 3409 to 5496 kcal/day and between 58.1 to 90.4 kcal/kg FFM. The mean daily energy expenditure for the group was 4281 ± 656 kcal/day.
The ratio of total energy expenditure to basal metabolic rates as estimated by the Schofield equation ranged from 1.93 to 3.18. There was no apparent correlation between the weight load carried by an individual and the energy expended above his estimated basal metabolic rate.

Activity Patterns: The weight load carried by each subject was determined by his position within the unit. Total weight of the subjects (body weight plus load) varied from 96 to 122 kg with a mean of 113 ± 9 kg. The weight load as a percent body weight varied from 34 to 78%. During maneuvers, heart rates ranged between 120 to 180 bpm over a repetitive periods of 2-3 hours. This corresponded to a moderate to heavy activity levels. During the remaining parts of the maneuver, heart rates ranged between 55 - 90 bpm.

Energy Intake: The total mean energy intake was 2858 ± 433 kcal/day, of which 2175 ± 379 kcal/day was provided by base supplied foods and 683 ± 288 kcal/day by privately provided foods. Carbohydrates, fats and proteins accounted for approximately 53, 34, and 13% of the total intake.

Energy and Protein Balance: Individual values for energy intake, expenditure and balance are given in table 2. Individuals mean energy balance ranged from -46 to -2296 kcal/day. Mean energy balance for the group over the 12 day study period was -1422 ± 628 kcal/day.

The contribution of protein oxidation averaged 10% of total energy expenditure. The mean protein balance was -20 kcal/day. However, there was a large inter-individual variation in the protein balance data.

Weight Changes: The mean of the individual differences in body weight between the start and completion of the study was minus 600(±900) grams. Individual changes in body weight are shown in figure 2. There were no apparent correlations

between weight change and caloric balance. In table 3, individual changes in body weight and their corresponding caloric equivalences are compared with the part of caloric balance that cannot be explained by weight change.

Climatic Conditions: Temperature, relative humidity and wind velocity over the course of the day are given in table 4.

DISCUSSION

The present study investigated energy expenditure and energy intake in infantry soldiers performing military maneuvers in cold climate conditions. We obtained a negative energy balance which was accompanied by a reduction in body weight.

The group studied in this work was very homogeneous in physical characteristics that may play a role in determining total energy expenditure (table 1). The values obtained for total body water and fat free mass were in excellent agreement with the values reported for other military personnel (12,13).

A high energy expenditure among troops performing military training and jungle manoeuvres have already been documented. Subjects in the present study, performing actual military maneuvers in a cold environment have reached mean daily energy expenditure of 4281±656 kcal/day. This falls between the values of 3400 ± 260 and 4750 ± 531 kcal/day reported by DeLany and Forbes, respectively (12,13).

The significance of adequate nutrition in combating to overcome the combination of physical activity and climatic stress is apparent. A prolonged exposure to cold will require the provision of adequate food above the minimum necessary in comfortable environment (14). Human protection from cold is mainly based on thermal insulation provided by clothing, since human physiological adaptation to cold is minimal. Vasoconstriction and shivering are effective for limited time periods thereafter survival depends on the ability to increase thermogenesis. This has been recently documented by Vallerand & Jacobs (4) reporting a 2.5-fold increase in energy expenditure during a 2h cold exposure at rest. This physiological mechanism is energy dependent, therefore, food intake, mainly carbohydrates, should increase to balance the elevated energy needs (4). In a paradoxical manner, there is mounting evidence that food intake in the field ranges between 60%-75% of the available calories and less than 80% of the nutritional standard (15,16,17). Even when a supplemental pack was added, energy intake still remained bellow the recommended consumption for training in cold conditions (1). These reports are in agreement with our findings, and as found by others is associated with a loss in body weight (1,12). The reasons for minimal food intake under field conditions was speculated to relate to water intake in a way that water consumption could influence food consumption and vice versa (1,18). In addition, military schedule does not always allow for organized meals and often troops are being called for an

unexpected duty, leaving them no time for meals or for Ready-to Eat field rations.

The change in body weight in our study ranged between a loss of 2600 to a gain of 600 grams; at this phase we did not assess body composition at the beginning and the end of the study period, but it could be speculated that the reduction in body weight was mainly due to loss of fat. It should be considered that these data represent a relatively short follow up of 12 days. Further loss of weight may be anticipated since the manoeuvre conditions remained unchanged for the entire winter season. If a negative energy balance persists for prolonged time periods, it is associated with a reduction in fat free mass which may lead to marked decrement in physical performance (19); its consequence in military life can not be overemphasized.

These data point to a high energy expenditure of infantry troops combating in a cold environment. Energy intake remained low and did not compensate for the increased expenditure. It was beyond the scoop of this work to evaluate separately the contribution of the intensed activity and that of the cold weather on the total expenditure; however, this study would be further extended during the summer season to assess energy balance under similar military maneuver in a hot climate.

Table 1: Subject Characteristics

Subject No.	Height (cm)	Weight (kg)	TBW (kg)	FFM (kg)	Fat Mass (% weight)
1	177	78.7	44.6	61.0	22
2	174	76.5	46.4	63.6	17
3	179	59.3	36.6	50.2	15
4	178	71.6	42.8	58.7	18
5	171	66.9	39.4	54.0	19
6	179	68.2	42.4	58.1	15
7	180	70.3	43.2	59.2	16
8	177	64.1	39.0	53.5	17
9	173	69.9	39.6	54.2	22
10	180	78.0	47.1	64.6	17
11	175	71.1	41.9	57.6	19
12	184	72.7	44.4	60.8	16
13	164	66.3	41.9	57.4	13
14	175	76.0	41.9	57.4	24
Mean	176	70.7	42.2	57.9	18
S.D.	5	5.3	2.8	3.8	3

Table 2. Individual energy intake, expenditure and balance (kcal/day)

Subject No.	Intake: Standard Military	Intake: Self Provided	TEE	Balance
1	2448	400	3900	-1052
2	1825	324	4203	-2054
3	1863	708	3492	-921
4	2026	1337	3409	-46
5	2159	516	4216	-1541
6	1840	861	3984	-1283
7	1952	470	3798	-1376
8	1700	839	3545	-1006
9	1932	672	4153	-1549
10	2222	716	5122	-2184
11	2143	373	4692	-2176
12	3079	646	5496	-1771
13	2567	507	5370	-2296
14	2697	1198	4554	-659
Mean	2175	683	4281	-1422
S.D.	379	288	656	628

Table 3*: Body weight changes, equivalence of weight and residual caloric balance, unexplained by weight change

Subject No.	BW Change (kg)	Caloric Equiv. of BW Change (kcal/day)	Residual Caloric Balance (kcal/day)
1	-1.90	-11.88	-136
2	-0.12	-75	1978
3	0.20	125	1046
4	-1.19	-744	-698
5	-0.33	-206	1335
6	0.61	381	1663
7	0.59	369	1745
8	0.36	225	1231
9	-1.10	-688	861
10	0.00	0	2185
11	-1.74	-1087	1088
12	0.10	62	1833
13	-0.50	-313	1983
14	-0.20	-125	534
15	-0.29		
16	-0.69		
17	-2.68		
18	-1.74		
Mean	-0.59	-375	1189
S.D.	0.92	570	806

* Table 3 includes BW data on 4 controls (no. 15-18), undosed subjects, that have no data on energy expenditure.

Table 4: Climatic conditions (mean±S.D., range) during the study period.

Time	Temp. (°c)	Relative Humidity (%)	Wind Velocity ($m \cdot sec^{-1}$)
08:00	8.3±2.6	75±23	8±6
	1.0-11.7	28-100	4-30
14:00	11.3±4.6	64±25	11±7
	3.0-21.2	24-100	2-25
20:00	8.5±3.0	72±23	11±9
	7-13.3	21-100	0-27
23:00	2.7±2.1	-	18.9±7.8
	0-7	-	10-35

Figure 1: Study protocol

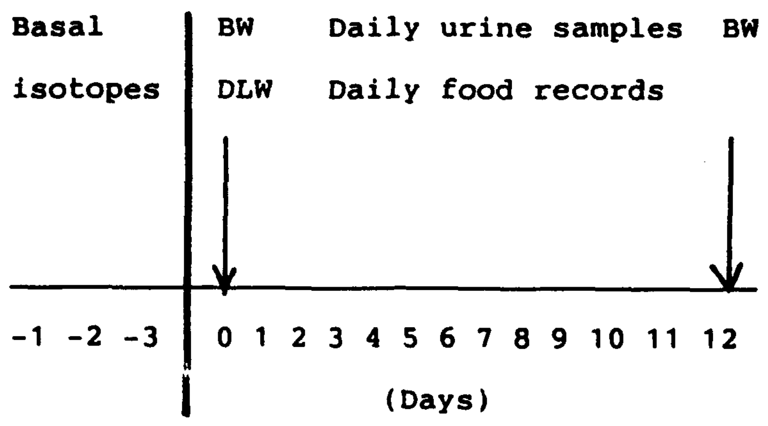
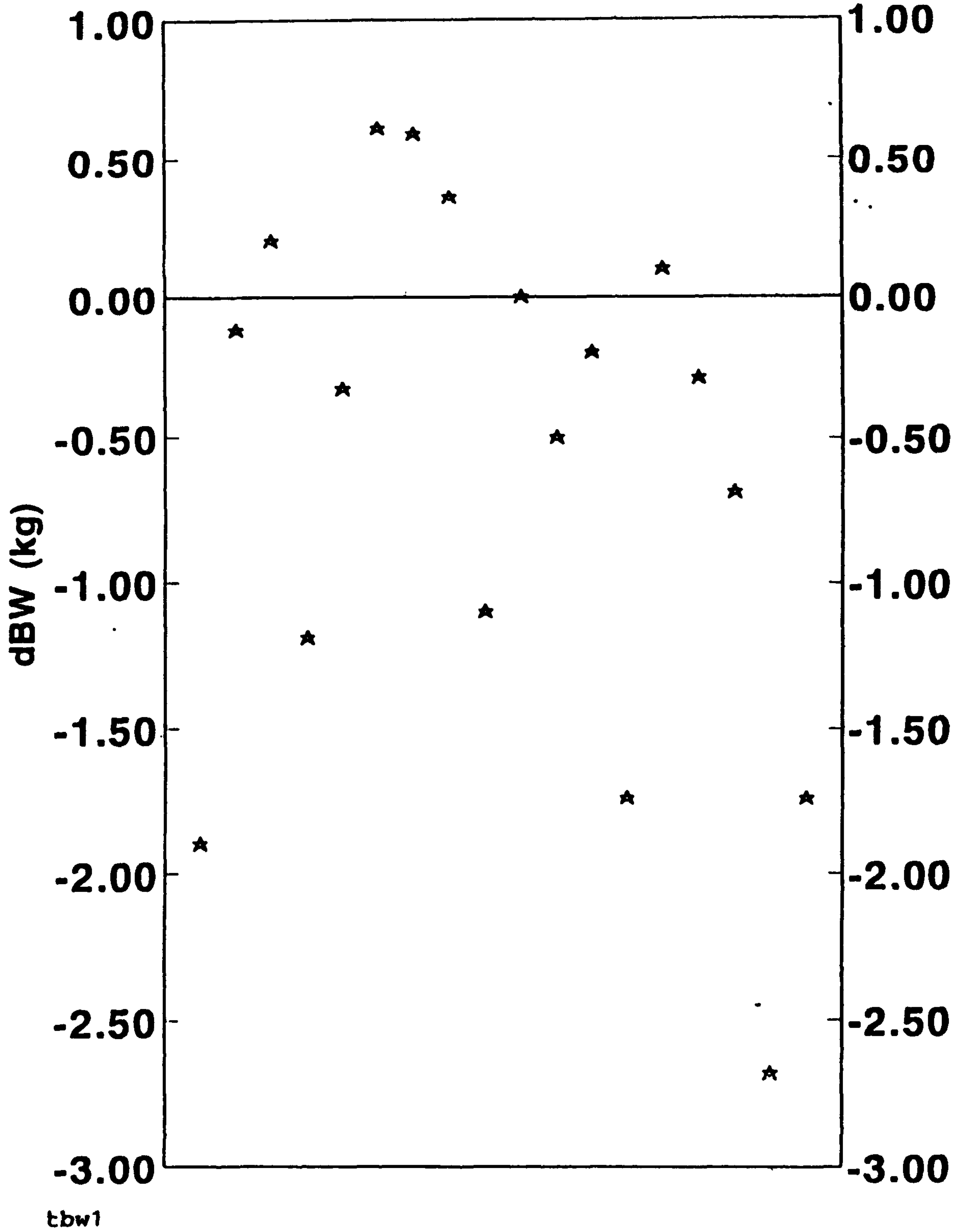


Figure 2: Individual changes in body weight (kg) during the study period.



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